The Contribution of Anthropometric Factors to Individual Differences in the Perception of Rhythm

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ABSTRACT: In a sample of 44 human subjects, aged between 18 and 38 years, two distinct measurement procedures were carried out: (1) a psychophysical procedure to determine 'preferred beat rate' and (2) standard anthropometry to determine mass and 6 skeletal dimensions. Additionally the factors of sex, age and musicianship were also assessed. ANOVAs were carried out with preferred beat rate as the dependent variable and each of the anthropometric variables as between-subjects factors, partitioned into two levels, defined by the 50th percentile. Significant effects were obtained for age, anthropometric factors and the interaction between age and sex, totalling about 40% of the explainable variance. No significant main effects of sex or musicianship were obtained.

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KEYWORDS: *rhythm, perception, beat induction, anthropometrics*

INTRODUCTION

THE process of beat induction—the activation of a regular isochronous pattern (the beat) when listening to regular temporal sequences—is fundamental to rhythm perception. For any sequence that is sufficiently regular to induce a beat percept, most aspects of the processing and coding of the sequence are strongly determined by the listener's choice of beat. Much work in rhythm perception over the last few years has therefore been devoted to trying to understand the process of beat induction (Clarke, 1999), and aside from purely theoretical accounts (e.g. most notably, Lerdahl and Jackendoff, 1983) there have been many attempts to model various aspects of the process, and to evaluate the models experimentally (for a review see Todd et al. 2002).

An issue of particular importance is the well-documented phenomena associated with the existence region of pulse sensation (Parncutt, 1994): a tactus (Lerdahl and Jackendoff, 1983) within a range of roughly 300-900 ms, and an upper and lower limit for pulse sensations (Fraisse, 1982; van Noorden and Moelants, 1999). Given the coincidence of the existence region with that of the cadence of spontaneous motor actions, such as locomotion, many authors have suggested that locomotion may indeed be the origin. It is of immense interest then to determine what, if any, relationship exists between beat induction and the body, particularly for the development of theoretical accounts of beat induction (Large and Jones, 1999; Todd et al. 1999, 2002).

The idea of a link between musical rhythm and physical motion can be traced back to antiquity (see Todd, 1995). It is also present across many cultures. Arom (1991) describes the way that across sub-Saharan Africa motor movement is seen as an inseparable component of music, with rhythm thought of as its stimulus. Thus, according to this view, our experience of "beat" is an imagined or actual movement, and as such, it is dependent on certain biomechanical features of our bodies as well as, ultimately, the conditioning of the physical environment. Further evidence for a link comes from numerous studies (see Fraisse 1982 for review) that individuals have a *preferred tempo*, as measured by the method of adjustment, and that the distribution of preferred tempi and the distribution of tempi in music are similar to the distribution of *spontaneous rhythmic movements*, including cadence in locomotion (Mishima, 1965), and *spontaneous tempo*, as measured by tapping. This suggests that the preferred tempo is a natural frequency which will be reflected in the biomechanical characteristics of locomotion. Beat induction has both perceptual and motor components (if a subject is asked to tap) and thus has characteristics of both preferred and spontaneous tempo.

A corollary of this putative link between beat induction and the body, is that given that every individual has a unique musculoskeletal system, then the way each individual hears a rhythm, i.e. where they place the beat in an auditory event sequence, will be determined by the unique dynamical and hence biomechanical properties of their individual bodies. In other words, in a population of individuals there should be a systematic relationship between the size of the body and beat induction. Although several studies have looked for a correlation between spontaneous tempo and preferred tempo (typical values up to about .4, Mishima, 1965), and between spontaneous tempo and anthropometric factors (Mishima, 1965; see also Treffner and Turvey, 1993), the possible links between preferred tempo and anthropometric factors, or between beat induction and anthropometric factors, have not been investigated (see Figure 1).

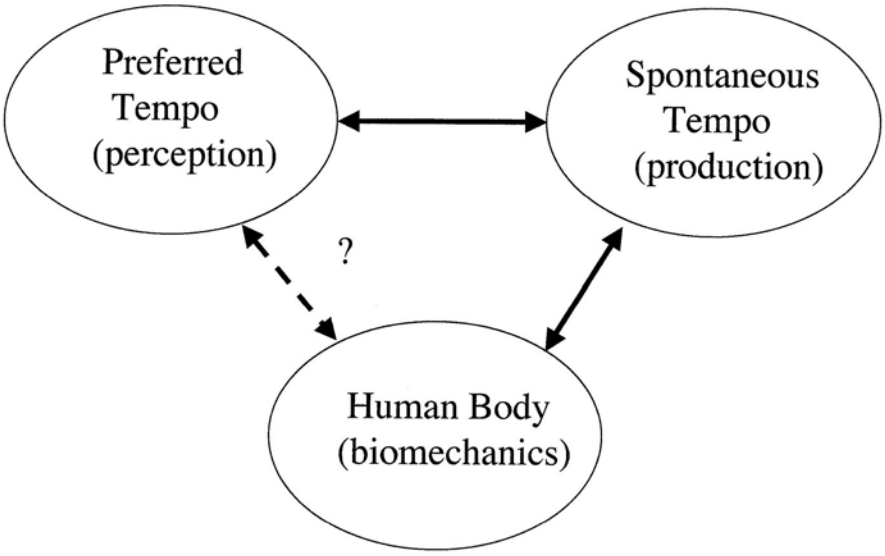
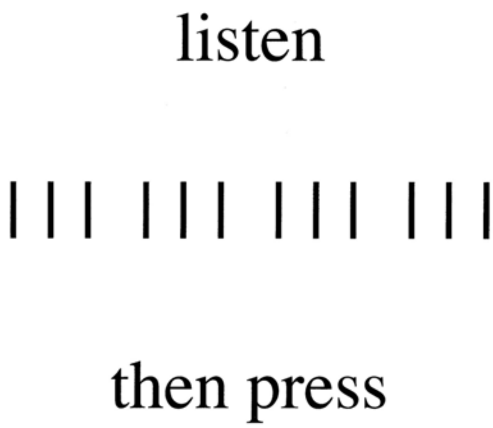


Fig. 1. The relationship between preferred tempo, spontaneous tempo and anthropometric factors.

Before running the experiment reported here, we ran a number of pilot experiments to develop a psychophysical procedure to measure beat induction and assess appropriate anthropometric measurements. We briefly describe this before going on to describe the main experiment.

(a)



(b)

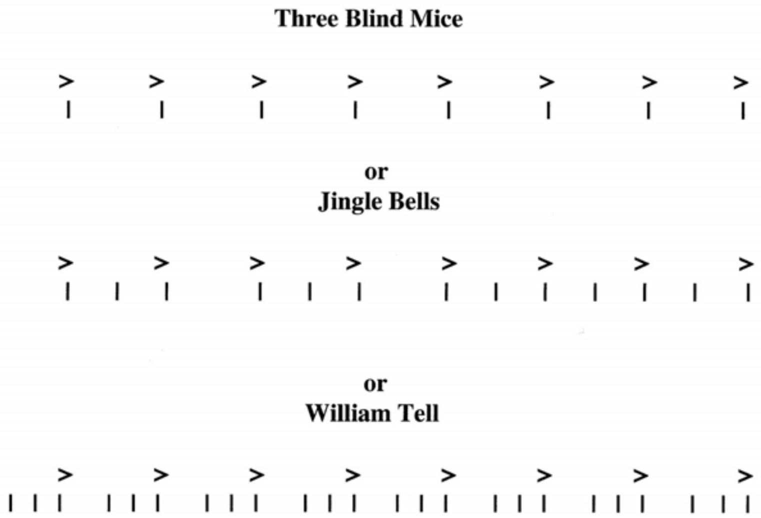


Fig. 2. Visual instructions for subjects. (a) A representation of the anapaest pattern of clicks. (b) A representation of beats in relation to the anapaest click sequence. A beat on every click corresponds to Three Blind Mice (TBM), on every second click to Jingle Bells (JGB) and on every third click to the William Tell Overture (WTO).

Rather than use previous methods for estimating preferred tempo, typically the method of adjustment (Fraisse, 1982), we have piloted a novel procedure using the method of constant stimuli to determine the purely perceptual component of beat induction, without contamination by actual motor movements. Our reasons for doing this is that we believe that adjusting a metronome lacks ecological validity since a simple metronomic beat does not have any metrical context. Also preferred tempo can be unreliable since it depends on the starting tempo. In our new method (described in more detail in the next section), an anapaest rhythm, consisting of a repeating pattern of SHORT SHORT LONG intervals defined by clicks, as in Figure 2a, is presented in random order at a fixed number of rates, ranged from fast to slow. In each trial subjects are asked to say whether they think the pattern most corresponds to one of three alternative rhythms, the William Tell Overture (WTO), Jingle Bells (JGB) or Three Blind Mice (TBM). The essential rhythmic difference between the three rhythms is where the beat is placed in relation to the individual click events (Figure 2b). In the case of TBM the beat comes on every click, for JGB on every two clicks, and for WTO on every third click. The resultant psychometric function gives the probability of a subject hearing JGB as a function of tempo. A number can then be estimated as the tempo at which JGB is most likely to be heard. This measure is highly reliable on retest. In order to distinguish it from preferred tempo we refer to this measure as *preferred beat rate*.

Having chosen the psychophysical procedure the next question is which are the critical anthropometric parameters? One obvious parameter to consider is leg length, since in most simple biomechanical models of human bipedal locomotion (see Alexander, 1995 for review), it is assumed that the cadence is given by leg length. The simplest model of this kind treats the leg as a pendulum so that the natural period is proportional to the square root of leg length. Another class of locomotive models, however, place the emphasis on the trunk as the principal determinant of cadence.

A fundamental assumption of the so called ‘spinal engine’ theory (Gracovetsky, 1992), is that the central role of the spine in the locomotion of lower vertebrates has been retained in human bipedal locomotion. Although the power source for human locomotion is the hip extensors, this power is transferred back to the spine, via gravity, in order to drive hip rotation. According to Gracovetsky (1992), the system has two resonant frequencies, depending on whether the transfer of gravitational energy to axial torque is mediated by muscle (walking) or ligament (running). Mathematical analysis indicates that the resonance frequency of the axial spinal system is dependent on the moments of inertia of the pelvis and thoracic elements and the elastic properties of the lumbar region.

Given the above theoretical considerations then, we chose the following anthropometic variables: mass M, height L_H, leg length L_L, biacromial (shoulder) breadth B_B, biiliac (hip) breadth B_I and bimalleolar (ankle) breadth B_M, since this is known to be a good predictor of (non-fat) frame size. Subjects were recruited over a six month period and were administered both psychophysical and anthropometric procedures. In order to ensure greater homogeneity, subjects were removed from the analysis if their Body Mass Index (BMI) was greater that 26 or less than 19. BMI, given by the mass divided by height squared, is the accepted parameter for obesity. The normal range is considered to be 20 - 25. In addition to anthropometric factors the sex, age and musicianship of subjects was noted.

METHOD

Subjects

The subjects were 44 members of the public from Manchester and students from Manchester University and the Royal Northern College of Music. The 44 subjects were divided as follows: by sex 20 males and 24 females, by musicianship, 14 music students and 30 non-music students and by age, 24 under 21 years of age and 20 over 20.

Apparatus

The click stimuli used for the anapaest rhythm were a single cycle of a 1 kHz square wave. The stimuli were generated by a MATLAB programme running on a PowerMac 4400/160 at a sampling rate of 10 kHz, amplified by a Kenwood KA-1080 stereo integrated amplifier and presented through Sennheiser HD480 headphones in an Industrial Acoustics sound attenuating cubicle. The clicks were arranged in the form of an anapaest rhythm: four repetitions of two SHORT (S) intervals followed by a LONG (L) interval, i.e. SSL SSL SSL SSL. Nine different rates were used, generated by the formula $S_i = 125 \times 2^{i/4}$ ms where $i = 1 \cdots 9$. The logarithmic formula is justified by the fact that time-interval discrimination approximately obeys Weber's Law. Subject responses were recorded from a response box with three buttons corresponding to the three alternative choices. Anthropometry was carried out using a standard anthropometer.

Procedure

Subjects were first screened for any neurological and hearing impairments, body deformation or chronic medication. Subjects were also excluded if their psychometric functions were non-monotonic or the maximum probability of the JGB function was less than 0.8. On this basis five subjects were discarded.

Subjects were told that in the experiment they were going to hear a number of rhythmic patterns and their task was to say whether the rhythm most reminded them of one of three alternatives: Three Blind Mice (TBM), Jingle Bells (JGB) or the William Tell Overture (WTO). The subjects were asked if they were familiar with these three tunes. They were then played exemplars of each in the form of metrical sine tone melodies, with short intervals of 125 ms, 280.6 ms and 706 ms respectively.

Subjects were asked if they knew what a beat is in music and asked to define it. Even if they could give a clear answer all subjects were told that a beat is “a regular pulse that you might tap your foot to or dance to in the case of music”. Subjects were then asked to tap the beat in synchrony with the exemplar rhythms. If they were unable to do this without instruction, the beat was demonstrated and they were allowed to repeat the task until they were able to synchronise with the beat.

It was then explained to them that during the experiment they would not hear melodies, but click rhythms at different rates, always consisting of four groups of three clicks. They were then shown the diagram in Figure 2a. Three versions of the anapaest rhythm were then played to them at the same rate as the exemplar melodies but consisting of clicks rather than tones. The two end intervals, 125 ms and 706 ms, were chosen to lie just outside the range of intervals used in the experimental trials, ensuring that subjects would be guaranteed to respond WTO and TBM respectively. The middle interval, 280.6 ms was chosen so that it did not coincide with any of the intervals in the experimental trials, but would be almost guaranteed to evoke a JGB response from the subjects. Subjects were asked in each case to identify which rhythm the click sequence most reminded them of.

They were then shown the diagram in Figure 2b and it was explained to them that “the essential rhythmic difference between the rhythms is where the beat comes in relation to each event, i.e. if the beat comes on every click the rhythm is TBM, if the beat comes on every second click the rhythm is JGB and if the beat comes on every third click the rhythm is WTO”. The same three versions of the anapaest rhythm were played and subjects asked to synchronise taps with the beat. If they were unable to do this without instruction, the beat was demonstrated and they were allowed to repeat the task until they were able to synchronise with the beat.

Subjects were then told that during the experiment the rhythms would be presented at a number of different rates which would vary randomly from one trial to the next. They were then presented with a sequence of 18 trials and were asked to tap the beat in each case. The subjects were then seated in the sound attenuating cubicle and shown a response box with the three alternatives clearly labelled. After fitting the headphones the subjects were given another run of 18 trials as practice, where their task was to press the response button according to Figure 2b. Before starting they were told that they must listen all the way to the end of the rhythm before pressing the button, and that they should not try to guess the response, since the presentation was completely random.

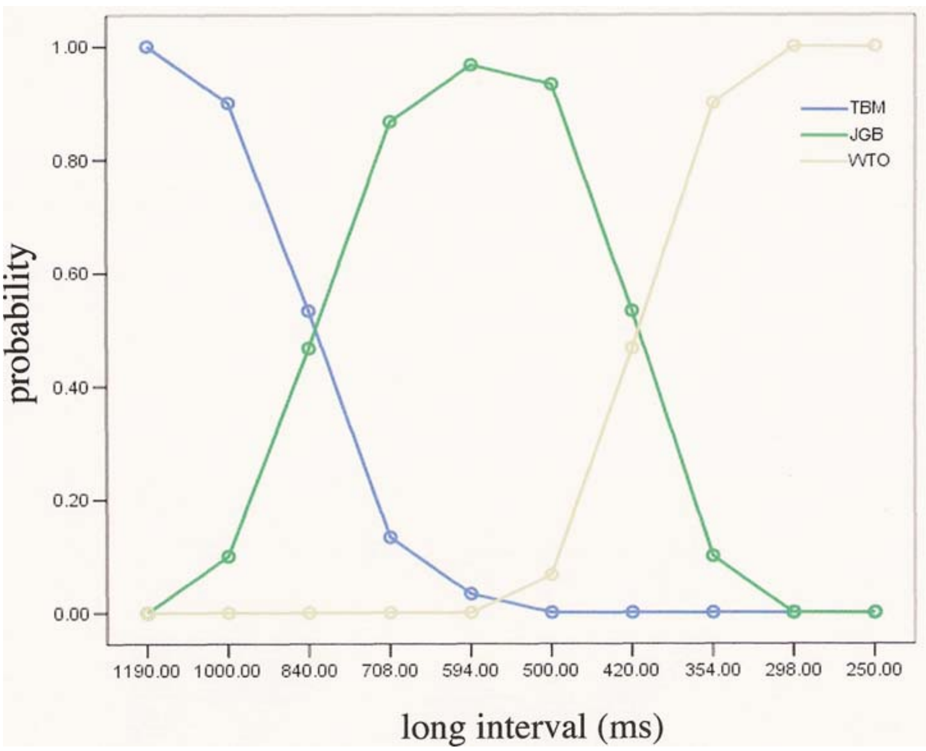
When the subjects were clear about the task, they were then given the first test run of trials which consisted of ten repetitions of each of the nine rates, i.e. 90 trials in total. After the first run was completed, anthropometry was carried out using standard procedures. Seven measures were obtained: stature, mass, sitting height, biacromial breadth, biiliac breadth and bimalleolar breadth. Leg length was estimated by subtracting sitting height from stature. Apart from mass, all measurements were made twice to obtain intra-experimenter error. At the start of the experiment, three experimenters compared measurements in order to determine inter-experimenter error. After anthropometry was completed, subjects were given a second run of 90 trials.

RESULTS

Reliability of Variables

From the subject responses we were able to obtain a psychometric function corresponding to the probability of subjects responding JGB as a function of the sequence rate. Figure 3 shows an example from one subject.

(a)



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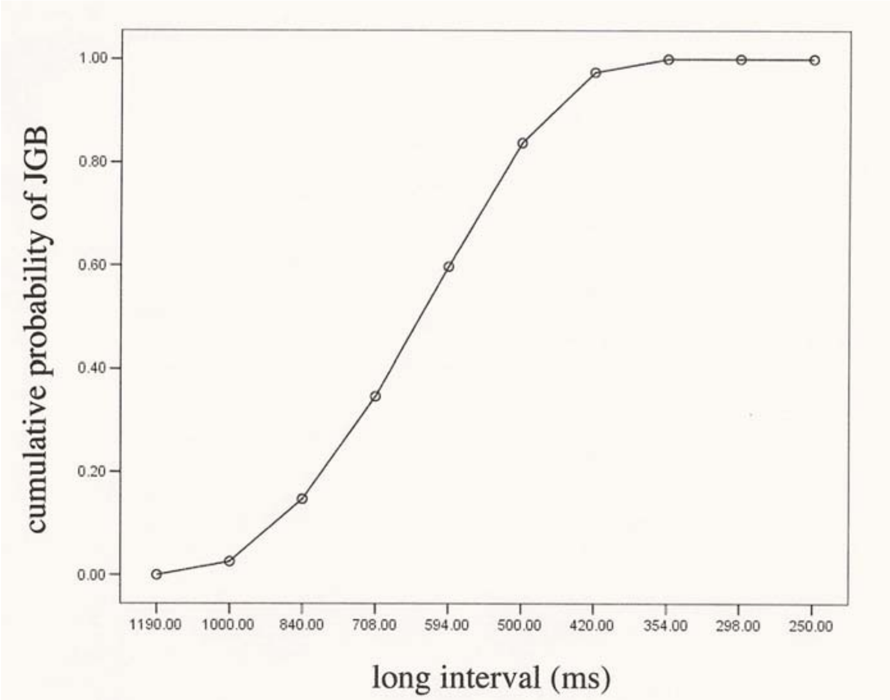

Fig. 3. (a) Psychometric functions for the three alternatives for one subject. (b) Normalised cumulative probability for the JGB psychometric function. Preferred beat rate is estimated to be the value at normalised cumulative probability 0.5.

Estimates of preferred beat rate were obtained by fitting a log logit function to the cumulative JGB distribution. This yielded a value of 540 ms (SD = 40 ms) and a test-retest reliability of 0.77.

Table 1. Descriptive Statistics for Anthropometry

	Men (n=20)				*Women (n=24)*			
	10th %le	50th %le	90th %le	SD	10th %le	50th %le	90th %le	SD
mass (kg)	62	73 (75)	81	8 (12)	51	61 (63)	67	6 (11)
stature	1668	1792 (1740)	1886	88 (70)	1606	1672 (1610)	1762	66 (62)
sitting height	863	947 (910)	971	41 (36)	838	873 (850)	928	40 (35)
leg	804	844	909	53	718	789	860	46
biacromial breadth	366	405 (400)	424	21 (20)	344	366 (355)	378	13 (18)
biiliac breadth	253	278	303	19	258	286	305	18
bimalleolar breadth	61	68	74	5	59	62	66	3

Values in parentheses are British average (Pheasant, 1990). All lengths in mm.

Anthropometric variables were also examined for reliability. Two estimates were used, test-retest correlations and the standard deviation of the error. Test-retest correlations were 1.00, 0.998, 0.991, 0.977 and 0.943 for height, sitting height, biacromial breadth, biiliac breadth and bimalleolar breadth respectively. The standard deviations of the error were 2.7 mm, 3.3 mm, 3.5 mm, 4.0 mm and 1.7 mm respectively. These values are within the range of experimenter error documented in the literature (Lohman et al. 1988). Table 1 shows the descriptive statistics of the anthropometric variables. Comparison with data for British adults (aged 19 - 65) indicates that our sample is slightly less than the average mass and less variable. In stature by contrast, our sample is about 4 - 6 cm taller than average. (Due to the unavailability of a female experimenter there are six missing values for hip and ankle breadth.)

Table 2. Correlation Matrix For Anthropometric Factors

	M	L_H	L_S	L_L	B_B	B_I	B_M
M	-						
L_H	.84	-					
L_S	.83	.88	-				
L_L	.68	.91	.60	-			
B_B	.80	.76	.75	.63	-		
B_I	.27	.28	.33	.19	.03	-	
B_M	.76	.86	.76	.79	.64	.26	-

Given that the sample had been constrained to lie between a BMI of 19 and 26 it is likely that all the anthropometric measures would be highly correlated. Table 2 shows the correlation matrix. As expected there was a high degree of correlation between each measure, except biiliac breadth. This was confirmed by a factor analysis which indicated two factors, the second factor comprising solely biiliac breadth.

Effects of Anthropometric and Non-Anthropometric Factors on Preferred Beat Rate

The effect of anthropometric differences on preferred beat rate was considered by means of ANOVA. In order to do this the male and female samples were separately divided into two groups, above median (A) and below median (B), according to the 50th percentile as in Table 1. There were thus 10 each of A and B males and 12 each of A and B females, making a total of 22 A and 22 B subjects. ANOVAs were carried out with preferred beat rate as the dependent variable and where measurement repetition was treated as a within-subjects factor. Although all the anthropometric variables, except biiliac breadth, contribute to a single body size factor, analyses were nevertheless also carried out separately in a one-way ANOVA for each anthropometric variable, since we were interested to determine which variables, if any, are better predictors of preferred beat rate. Non-anthropometric between-subjects factors age, sex and musicianship were analysed jointly in a three-way ANOVA (except for the two-way interaction between age and sex).

Table 3a. ANOVA for Non-Anthropometric Factors

factor	df	F	p	effect	h^2
within-subjects					
repetition	1,36	0.026	0.872	-1.90 ms	2.1%
repetition*sex	1,36	7.556	<.01	-20.94 ms (M) 13.00 ms (F)	22.4%
between-subjects					
sex	1,36	1.361	0.251	-10.08 ms 3.8%	
age	1,36	6.643	<.05	-29.5 ms	17.6%
musicianship	1,36	0.181	0.15	-5.34 ms	0%
sex*age	1,40	3.092	0.086	-52 ms (M) -10.8 ms (F)	7.2%

Table 3b. ANOVA for Anthropometric Factors

factor	df	F	p	effect (B-A)	h^2
M	1,41	7.63	<.01	-32.04 ms	15.7%
L_H	1,42	5.28	<.05	-27.04 ms	11.2%
L_S	1,42	2.77	0.10	-20.10 ms	6.2%
L_L	1,42	6.17	<.05	-28.94 ms	12.8%
B_B	1,42	6.02	<.05	-28.62 ms	12.5%
B_I	1,36	0.02	0.90	-1.61 ms	0%
B_M	1,36	2.27	0.14	-19.80 ms	5.9%

Table 3a and 3b shows the results of the ANOVA with preferred beat rate as the dependent variable. There were no significant main effects of sex or musicianship. There was no main effect of measurement repetition, consistent with the reliability measure above, but there was a significant interaction with sex, with the male subjects about 20 ms slower in the second block of trials. There was a significant main effect of age such that the under 21 group were about 30 ms faster than the over 20 group. Although the interaction between sex and age did not reach significance, the slowing down with age was largely due to males, -54 ms vs -12 ms respectively. Four of the anthropometric factors, mass, height, leg length and biacromial breadth produced significant main effects. The effect size ranged from about 27 ms to 32 ms in the predicted direction, i.e. the above median group had significantly longer preferred periods (or slower preferred beat rates) than the below median group, accounting for up to 16% of the variance
.

Table 3c. Pair-wise ANCOVA of anthropometric factors

	covariate						
factor	M	L_H	L_S	L_L	B_B	B_I	B_M
M	-	*	**	**	**	**	**
L_H	ns	-	ns	ns	ns	**	**
L_L	ns	ns	*	-	*	**	*
B_B	ns	ns	*	*	-	**	*

* <.1, **<.05

In order to further assess which anthropometric factors were dominant, a pair-wise ANCOVA was carried out, shown in Table 3c. The general pattern is that mass is the predominant factor, i.e. it is largely independent of the other factors, followed by leg, biacromial breadth and height.

DISCUSSION

Interpretation of Effects Due to Anthropometric Factors

Although the anthropometric effects are statistically significant, it may be considered that the effect size is not large. However, these results are consistent with the previous literature. An h^2 of 16% corresponds to a biserial correlation coefficient h of 0.4, which is in line with Mishima's results. It would be surprising if the relationship between anthropometric factors and perception was stronger than the relationship between anthropometric factors and action. In order to further investigate the magnitude of this effect, though, we compare several relative measures which we show in Table 4a.

TABLE 4a Comparison of Effects and Relative Effects Across Anthropometric Factors

	Dependent Variable				**Independent Variable**			
	Male		**Female**		**Male**		**Female**	
	ΔT	$\Delta T / \bar{T}$	ΔT	$\Delta T / \bar{T}$	ΔL	$\Delta L / \bar{L}$	ΔL	$\Delta L / \bar{L}$
M	-27.2 ms	5.9%	-36.3 ms	6.7%	13.2 kg	18%	9.3 kg	15.2%
L_L	-27.1 ms	5.4%	-30.4 ms	5.6%	77 mm	9.1%	65 mm	8.2%
B_B	-26.9 ms	5.0%	-30.0 ms	5.5%	32 mm	7.9%	20 mm	5.5%
L_H	-32.6 ms	6.1%	-22.7 ms	4.2%	133 mm	7.4%	94 mm	5.6%

TABLE 4b Comparison of Effect Slopes Across Anthropometric Factors

	$\frac{\Delta T}{\Delta L}$		$\left(\frac{\Delta T}{\Delta L}\right) \cdot \left(\frac{\bar{L}}{\bar{T}}\right)$	
	Male	**Female**	**Male**	**Female**
M	2.06 ms/kg	3.9 ms/kg	0.32	0.44
L_L	0.35 ms/mm	0.47 ms/mm	0.59	0.68
B_B	0.84 ms/mm	1.5 ms/mm	0.63	1.00
L_H	0.24 ms/mm	0.24 ms/mm	0.82	0.75

Examination of Table 4a shows that for males the relative effect varies between about 5 - 6% of the mean preferred beat rate and between about 4 - 7% for females, although the difference between the effect for males and females is not significant. This corresponds to a change of 7 - 18% in the anthropometric factors for males and 5.5 - 15% in females. The general trend is that the larger the relative difference between the below and above median groups in the anthropometric factor the greater the effect on preferred beat rate, as would be expected. Thus given that body mass is the strongest differentiator of the A and B groups, in general it produces the largest effect. However, when the effects are considered in relative terms (Table 4b) the picture is somewhat different. If one compares the ratio of effect size to relative difference in anthropometric factors, the body spatial dimensions appear more efficacious than body mass. In particular for females a 5.5% change in biacromial breadth produces an effect size of 5.5%, a ratio of 1.0, and for males a 7.4% change in height produces and effect size of 6.1%, a ratio of 0.82. This compares with ratios of 0.44 and 0.32 for the relative effect of body mass. Consideration of effect slope, i.e. the ratio of absolute effect to change in independent variable, indicates that of the spatial dimensions biacromial breadth is by far the most efficacious factor for both males and females.

As a further check on the above effect values it is worth considering what effect sizes would be predicted by simple biomechanical considerations. In the introduction we discussed two distinct classes of model. The first, in its simplest form, views the cadence of locomotion as being determined by the leg as a simple gravity pendulum such that

$$T = 2\pi\sqrt{\frac{cL}{g}} \tag{1}$$

where c is a constant giving the centre of mass of the leg as a proportion of its length and g is acceleration due to gravity. The second considers the cadence of locomotion to be determined by the torsional motion of the whole body where the period is determined by the ratio of the moment of inertia to a torsional stiffness. Given the considerable uncertainty concerning the value of torsional stiffness, however, we restrict the following analysis to the simple pendulum.

In order to determine estimates we note first that when comparing the cadence of locomotion to beat rates in music, the period of a single leg-swing corresponds to half the beat period. Thus the predicted effect will be given by

$$T_A - T_B = \pi\left[\sqrt{\frac{cL_A}{g}} - \sqrt{\frac{cL_B}{g}}\right] \tag{2}$$

which yields values of -29 ms and -26 ms respectively for males and females if c = 1/2, i.e. the leg is treated as a uniform rod with centre of mass at one half leg length. These slightly overestimate the male values and slightly underestimate the female values. Closer estimates may be obtained by a least-squares fit of the regression equation $Y = cL$ where

$$Y = \left(\frac{T}{\pi}\right)^2 g \tag{3}$$

which yields values of c = 0.34 and DT = 24 ms for males and c = 0.38 and DT = 29 ms for females. This would imply that the centre of mass is closer to 1/3 rather than 1/2 leg length, which is not unreasonable.

Interpretation of Effects Due to Non-Anthropometric Factors

Although there is no main effect of sex, sex interacts significantly with measurement repetition and has a close to significant interaction with age. In both cases the interaction is due to the male subjects, who are both more variable and slow down more with age.

One obvious account of the age effect might be to do with anthropometric differences, i.e. the young males might be smaller than the older males. Examination of the data, however, shows that this explanation can be ruled out. First, ANOVA with the dominant anthropometric factors as the dependent variable and age and sex as between subjects factors shows neither main effects of age nor an interaction between age and sex. (There is of course a highly significant main effect of sex, the males being larger than the females.). Second, ANCOVA with the dominant anthropometric factors as covariates does not alter the significance level of the age*sex interaction. Anthropometric differences can therefore be ruled out as the basis of the age effect. As for the result that males are less reliable than females we do not have an explanation.

GENERAL DISCUSSION

The above results indicate that anthropometric factors provide a significant contribution to individual differences in preferred beat rate. The magnitude of this contribution is about 16% of variance, which is consistent with previous literature (Mishima, 1965). The effect size, about 30 ms, is also consistent with a biomechanical explanation. The case for a relationship with locomotion is further strengthened when we consider the distribution of preferred beat rates and distribution of cadence in locomotion. According to Whittle (1996) the range of cadence for walking is approximately 430 - 660 ms. In our data the range of preferred beat rate is 451 - 635 ms.

It might be argued that the effect of anthropometric factors on preferred beat rate is not actually a direct one, i.e. it is mediated by an internal representation of common rates of spontaneous actions, such as walking, rather than an internal representation of the body itself (see Figure 1). However, given that spontaneous actions are constrained by biomechanics (Treffner and Turvey, 1993), and that motor planning of action, including locomotion, requires an internal feedforward model of body dynamics (Miall et al. 1983), then it would seem odd if the brain did not make use of this information in the perception of rhythm. This is particularly so given also that there is now considerable evidence that the cerebellum, thought to be the locus of forward models of the body, plays a role in temporal perception (Ivry and Keele, 1989).

Why then is there an age effect with the males? We have already ruled out anthropometric differences and can provide no *a priori* explanation. However, if one considers the literature on adolescent growth patterns a number of factors are striking. First, the peak in the growth velocity is quite different for males and females. Whereas for males the peak growth velocity in height is at the age of 14, for females the peak is between 11 and 12 years. By the age of 17 - 18 female growth in height has almost completely ceased, but males in the 75th percentile are still growing at about 1 cm per year, while males in the 90th percentile are still growing at over 2 cm per year. For sitting height there is a similar peak in growth velocity. At the age of 18 for males in the 75th percentile the growth rate is about 1 cm per year, while for females in the 75th percentile the growth rate is about 0.5 cm per year. For biacromial breadth males in the 90th percentile are still growing at about 1 cm per year whilst females in the 90th percentile have almost completely stopped. From these data it is clear that above average height males will still be growing at 18 (and possibly 19 for the very tall males). In our sample the 50th percentile was about 5 cm greater than the average for the males, and the under 21 males taller still: it is almost certain therefore that some of the 18 and 19 year old males were still growing, whereas the females would be almost completely finished growing.

On their own, sex differences in growth patterns are not enough to explain why the males showed age effects but the females did not, particularly since there is no significant difference between the over and under 21 males in anthropometric factors. In order for differential growth patterns to explain the age effects it is necessary for there to be a time-lag in sensory-motor recalibration of a year or so, i.e. a time-lag for the brain to 'catch up' with the change in the body. Recently, evidence has been presented that the time-scale of perceptuo-motor recalibration does indeed have significant effects in fast growing males on both their motor skills and self-judgements of reach (Heffernan, 1998). Given this evidence it is quite plausible to suppose that there may be a further learning lag in specifically auditory-motor judgements, even if the system has adapted to the new anthropometric dimensions for visually guided action. The fact that under 21 males behave as if they are smaller versions of themselves is consistent with such a time-lag. However, such speculations require further experimentation to be resolved. A follow up study of rhythm perception in adolescents would be appropriate. We would predict in particular that the change in preferred beat rate should show that same velocity profile that is evident in adolescents' growth, but with a well-defined time lag.

Irrespective of the source of the age effect, in our sample it contributes about 18% of the variance. Together with the contribution from the age/sex interaction and anthropometric factors this gives a total of 40% of the variance explainable in terms of these three factors. The significantly larger male variability contributes 22.4% which leaves some 38% of the total variance to be explained. At this stage we may only speculate as to the sources of this unexplained variance, but musicianship and sex may be ruled out.

CONCLUSION

In this paper we have provided evidence that anthropometric factors and other factors, including age and sex, contribute to individual differences in the perception of rhythm. Although anthropometric factors contributes only about 16% (corresponding to a correlation of 0.4) to the total variability, the magnitude of the effect, about 30 ms, and coincidence of the mean values of preferred beat rate with the cadence of locomotion, lend further support to the view that the human body plays an important role in the perception of rhythm.

REFERENCES

Alexander, R.N. (1995). Simple models of human movement. *Applied Mechanics. Reviews,* Vol. 48 No. 8, pp. 461-469.

Arom, S. (1991). *African Polyphony and Polyrhythm*. Cambridge: Cambridge University Press.

Buckler, J. (1990). *A Longitudinal Study of Adolescent Growth*. London: Springer-Verlag.

Clarke, E.F. (1999). Rhythm and timing in music. In D. Deutsch (Ed.), *The Psychology of Music*. 2nd Edition. NY: Academic Press.

Fraisse, P. (1982). Rhythm and tempo. In D. Deutsch (Ed.), *The Psychology of Music*. New York: Academic Press.

Gracovetsky, S. (1990). Musculoskeletal function of the spine. In J.M. Winters & S.L-Y. Woo (Eds.), *Multiple Muscle Systems: Biomechanics and Movement Organization*. New York: Springer-Verlag

Heffernan, D. (1998). *Perceptuo-Motor Calibration and the Perception of Affordances Following Rapid Growth in Adolescence.* Doctoral thesis, University of Strathclyde.

Ivry R.B. and Keele S.W. (1989). Timing functions of the cerebellum. *Journal of Cognitive Neuroscience,* Vol. 1 No. 2, pp. 136-152.

Large, E. and Jones, M. R. (1999). The dynamics of attending. *Psychological Review,* Vol. 106, pp. 119-159.

Lerdahl, F. and Jackendoff, R. (1983). *A Generative Theory of Tonal Music*. Cambridge, MA: MIT Press.

Lohman, T., Roche, A., and Martorell, R. (1988). *Anthropometric Standardization Reference Manual*. Champaign, IL: Human Kinetics Books.

Newman, F.H. and Searle, V.H. (1957). *The General Properties of Matter*. London: Arnold.

Miall, R.C., Weir, D.J., Wolpert, D.M. and Stein, J.F. (1993). Is the cerebellum a Smith predictor? *Journal of Motor Behavior,* Vol. 25 No. 3, pp. 203-216.

Mishima, J. (1965). *Introduction to the Morphology of Human Behaviour: The Experimental Study of Mental Tempo.* Tokyo: Tokyo Publishing.

Parncutt, R. (1994). A perceptual model of pulse salience and metrical accent in musical rhythms. *Music Perception,* Vol. 11, pp. 409-464.

Pheasant, S. (1990). *Anthropometrics: An Introduction*. Milton Keynes: British Standards Institution.

van Noorden, L. and Moelants, D. (1999). Resonance in the perception of musical pulse. *Journal of New Music Research,* Vol. 28, pp. 43-66.

Todd, N.P. McAngus (1995). The kinematics of musical expression. *Journal of the Acoustical Society of America,* Vol. 97 No. 3**,** pp. 1940-1949.

Todd, N.P. McAngus, Lee, C.S. and O'Boyle, D.J. (1999). A sensory-motor theory of rhythm, time-perception and beat induction. *Journal of New Music Research,* Vol. 28, pp. 43-66.

Todd, N.P. McAngus, Lee, C.S. and O'Boyle, D.J. (2002). A sensory-motor theory of temporal tracking and beat induction. *Psychological Research,* Vol. 66, pp. 26-39.

Treffner, P.J. and Turvey, M.T. (1993). Resonance constraints of rhythmic movement. *Journal of Experimental Psychology: Human Perception and Performance,* Vol. 19, pp. 1221-1237.

Whittle, M. (1996). *Gait Analysis.* Oxford: Butterworth-Heineman.